Field and Charge Penetration by Lightning Burnthrough

Sandia National Laboratories

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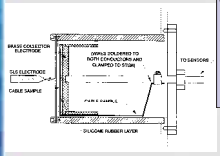
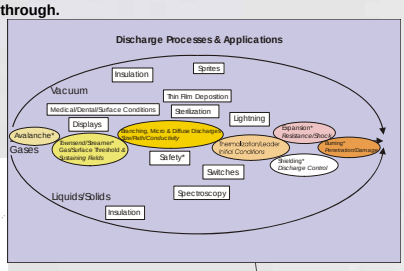
Problem

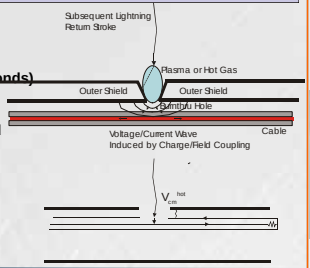
Lightning will burn through metallic enclosures. This LDRD will develop a quantitative understanding of the physical principles that limit voltage and current penetration in lightning burnthrough.

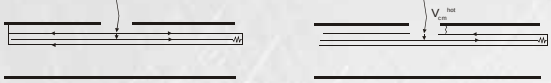




Many time phases of electrical discharge development (from subnanosecond to seconds) are relevant to this problem.

The problem is important for designing and assessing shielding for safety critical components.

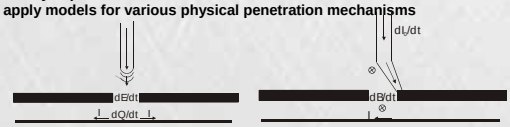




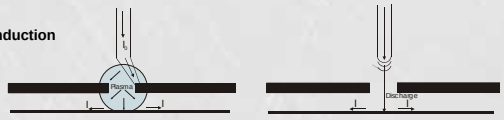
Approach

Methodology includes:
- **Decompose problem into fundamental coupling components**
- **Carry out discovery experiments**
- **Develop and apply models for various physical penetration mechanisms**

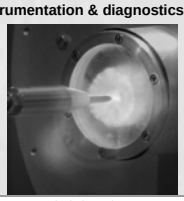
Indirect
- **Electric**
- **Magnetic**

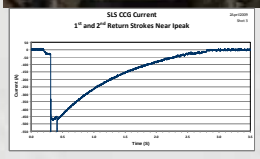


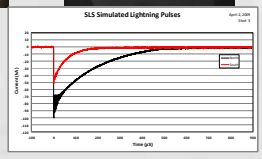
Direct
- **Plasma conduction**
- **Arcing**



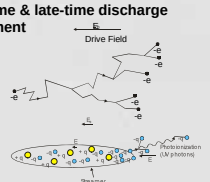
Experiments
- **Sandia Lightning Simulator (continuing current & return strokes)**
- **Discovery experiments involve detailed instrumentation & diagnostics**

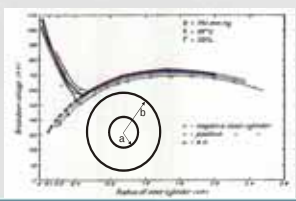






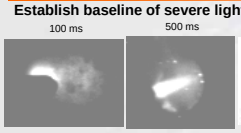
Penetration analysis & modeling
- **Electromagnetic coupling mechanisms**
- **Early-time & late-time discharge development**

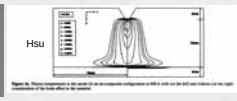


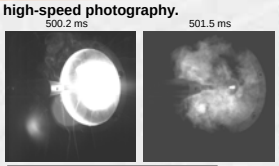


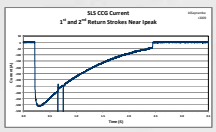
Results

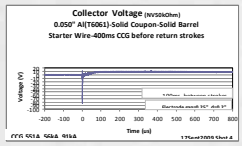
Establish baseline of severe lightning burnthrough response with high-speed photography.

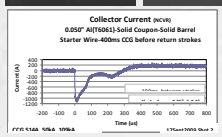






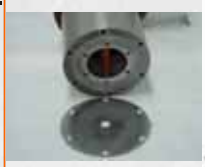


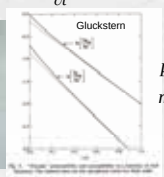




Measure and model indirect coupling responses to establish linear coupling response.

$$\Phi_{eq} = \mu_0 \left(\underline{H}_0 / I_0 \right) \cdot \underline{\alpha}_m \cdot \underline{H}^{sc} \quad , \quad V_{eq} = \frac{\partial}{\partial t} \Phi_{eq}$$





$t \approx 0.05$ in

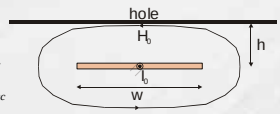
$2a \approx 0.5$ in

$p_z = 2\varepsilon_0 \alpha_{ezz} E_z^{sc}$

$m_x = -2\alpha_{mxx} H_x^{sc}$

$\alpha_e \approx 0.5 \alpha_e^0$

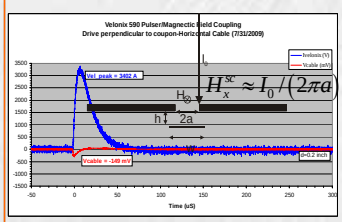
$\alpha_m \approx 0.5 \alpha_m^0$



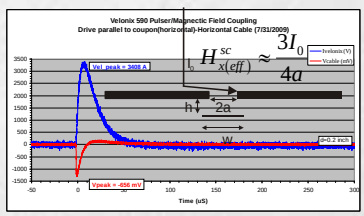
$h \approx 0.2$ in

$w \approx 0.5$ in

$wH_x^0 / I_0 \approx 0.5$



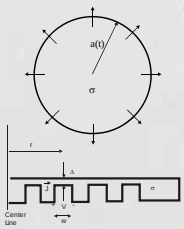
$H_x^{sc} \approx I_0 / (2\pi a)$

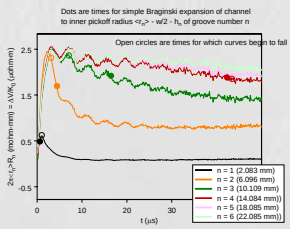


$H_{x(eff)}^{sc} \approx \frac{3I_0}{4a}$

$0.15 \text{ volts} < V_{mod}^{mag} < 0.66 \text{ volts}$ $\quad 0.21 \text{ volts} < V_{exp}^{mag} < 0.76 \text{ volts}$ $\quad \frac{dI_0}{dt} \le 400\text{kA}/\mu\text{s} \rightarrow 0.1\text{kV} < V_{max} < 0.5\text{kV}$

Develop an understanding for plasma current distribution during continuing current to return stroke transition.

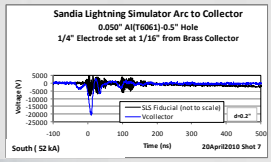




Develop arcing threshold models to guide and interpret measurements of interior arcing potentials.

$$\exp\left[\int_C \alpha(E) d\ell\right] = N$$

Pin position (mm)	Cable Position (mm)	Protection Factor
6	6	3.4
5	5	2.2
4	4	1.3
2.5	2.5	none
2.5	5	1.2
2.5	7.5	2.8
5	2.5	none
7.5	2.5	1.3



Significance

Will advance our understanding of how charges and fields penetrate burnthrough holes.

Will allow more realistic assessments of the severity of a burnthrough problem.

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